Miscellaneous Paper CHL-97-2
March 1997

US Army Corps
of Engineers
Waterways Experiment
Station

Evaluation of Wave Transmission Characteristics of OSPREY Wave Power Plant for Noyo Bay, California

by Jeffrey A. Melby, WES
William Appleton, San Francisco District

Prepared for U.S. Army Engineer District, San Francisco

Miscellaneous Paper CHL-97-2
March 1997

Evaluation of Wave Transmission Characteristics of OSPREY Wave Power Plant for Noyo Bay, California

by Jeffrey A. Melby

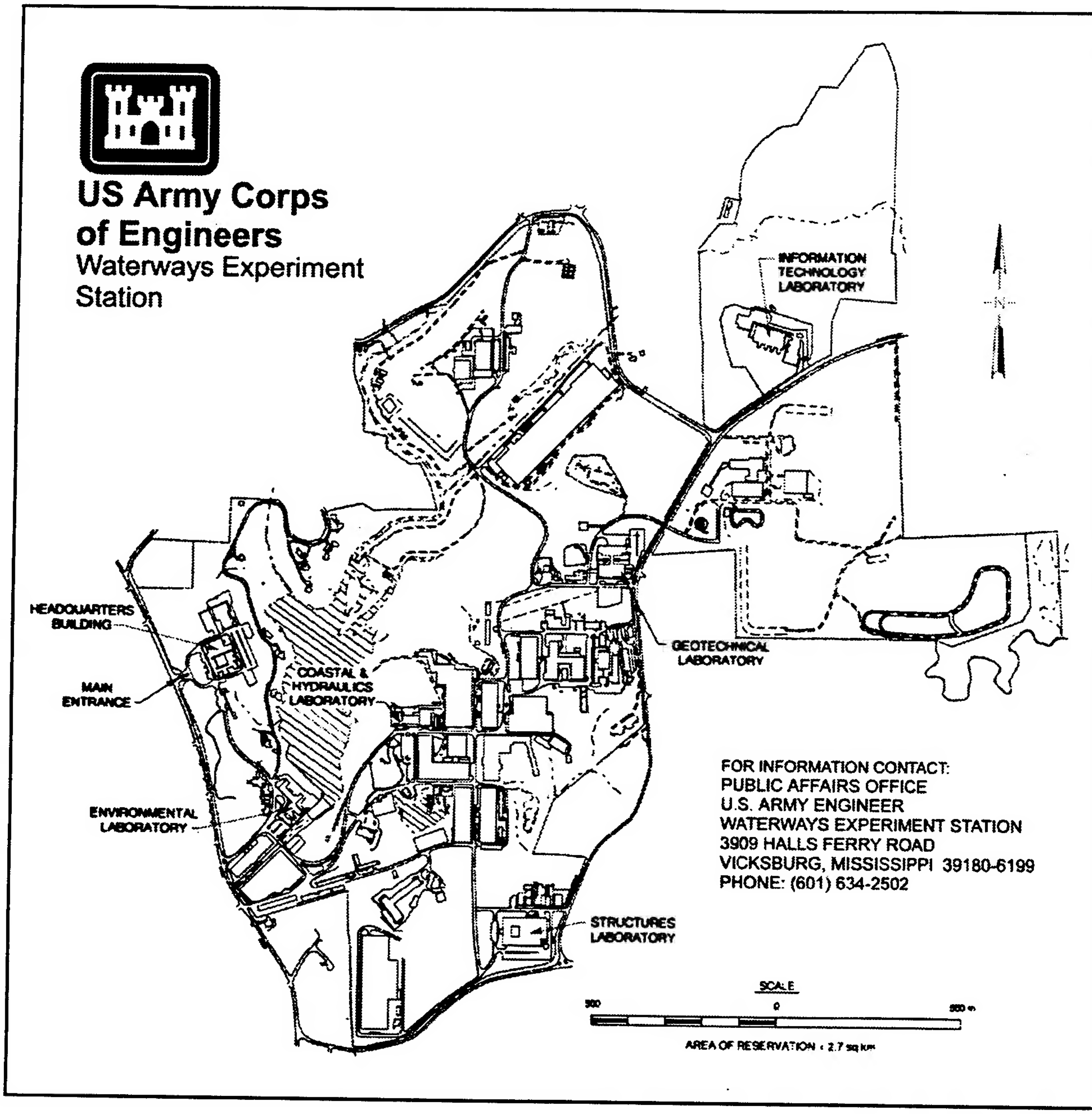
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

William Appleton

U.S. Army Engineer District, San Francisco
333 Market Street
San Francisco, CA 94105-1905

Final report

Prepared for U.S. Army Engineer District, San Francisco
San Francisco, CA 94105-1905



Waterways Experiment Station Cataloging-in-Publication Data

Melby, Jeffrey A.

Evaluation of wave transmission characteristics of OSPREY Wave Power Plant for Noyo Bay, California / by Jeffrey A. Melby, William Appleton ; prepared for U.S. Army Engineer District, San Francisco.

42 p. : ill. ; 28 cm. — (Miscellaneous paper ; CHL-97-2)

Includes bibliographic references.

1. Ocean waves — California — Noyo Bay — Testing. 2. Water waves — California — Noyo Bay — Testing. 3. Rubble mound breakwaters. 4. Hydraulic models — Analysis. I. Appleton, William. II. United States. Army. Corps of Engineers. San Francisco District. III. U.S. Army Engineer Waterways Experiment Station. IV. Coastal and Hydraulics Laboratory (U.S. Army Engineer Waterways Experiment Station) V. Title. VI. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; CHL-97-2.

TA7 W34m no.CHL-97-2

Table of Contents

Preface v

1—Introduction 1
Purpose 1
Goals 1
Background 1

2—Experiment 6
Experimental Setup 6
Wave Data Analysis 9
Wave Transmission Characteristics 16

3—Conclusions 21

References 22

Appendix A: Experimental Results Summaries A1

SF 298

List of Figures

Figure 1. OSPREY 1 2

Figure 2. Elevation view of OSPREY 1 showing OWC and turbines 2

Figure 3. Idealized schematic of OWC 3

Figure 4. Wells turbine/generator 4

Figure 5. Conceptual drawing showing "antenna focussing" 4

Figure 6. Wave flume plan and elevation views 7

Figure 7. Plan 2: Three OSPREY in flume 8

Figure 8. Plan 3: Four OSPREY in flume 8

Figure 9. Wave gauge time series for 13-sec, 6-m regular wave test 11

Figure 10. Wave gauge time series for 20-sec, 4-m regular wave test 12

Figure 11. Measured versus expected incident regular wave height with no structure in flume for various analysis methods 13

Figure 12. Measured versus expected incident irregular wave height with three OSPREY in flume for various analysis methods 15

Figure 13. Incident versus transmitted regular wave height for 13-sec period. Three OSPREY compared to rubble mound. 17

Figure 14. Incident versus transmitted regular wave height for 20-sec period. Three OSPREY compared to rubble mound. 17

Figure 15. Incident versus transmitted irregular wave height for 9-sec period. Three OSPREY compared to four OSPREY. 18

Figure 16. Incident versus transmitted irregular wave height for 13-sec period. Three OSPREY compared to four OSPREY. 19

Figure 17. Incident versus transmitted irregular wave height for 20-sec period. Three OSPREY compared to four OSPREY. 19

List of Tables

Table 1. Spacing of OSPREY Arrays as Tested for Wave Transmission . . . 9

Table 2. Approximate Transmission Coefficients for Regular Wave Flume Tests, 16-m Prototype Depth 18

Table 3. Approximate Transmission Coefficients for Irregular Wave OSPREY Flume Tests 20

Table A1. Experiment Log

Table A2. Experiment Results at Prototype Scale

Preface

Funding for the Noyo Bay Breakwater Study, as discussed in this report, was provided by the U.S. Army Engineer District, San Francisco (SPN).

The work was carried out between October, 1995 and June, 1996 by Mr. Jeffrey A. Melby, Research Engineer, U.S. Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory (CHL) and Mr. William Appleton, Project Engineer, SPN. The CHL was formed in October 1996 with the merger of the WES Coastal Engineering Research Center and Hydraulics Laboratory. Dr. James R. Houston is the Director of the CHL and Messrs. Richard A. Sager and Charles C. Calhoun, Jr., are Assistant Directors. The flume tests were funded by Applied Research and Technology (ART), Inverness, Scotland, and carried out at the ART laboratory by ART engineers and technicians during the period 17 through 24 March, 1996. These tests were supervised, the data analyzed, and this report written by Messrs. Melby and Appleton. Mr. Melby was under the direct supervision of Mr. C. Gene Chatham, Chief, Wave Dynamics Division, and Mr. D.D. Davidson, Chief, Wave Research Branch, CHL. Mr. Appleton was under the Supervision of Mr. Carlos Hernandez, Section Chief, Mr. Ken Kuhn, Chief of Design Branch, and Mr. Thomas Kendall, Acting Chief of Engineering, all of SPN. Mr. Davidson and Mr. George Hagerman, Seasun Technologies, provided technical review of this report.

At the time of preparation of this report, Dr. Robert W. Whalin was Director of WES and COL Bruce K. Howard, EN, was Commander.

1 Introduction

Purpose

Between 17 and 24 March 1996, the authors traveled to Inverness, Scotland. The purpose of the travel was to visit the Applied Research and Technology, Inc. (ART) laboratories and evaluate the ART OSPREY (Ocean Swell Powered Renewable EnergY) wave power plant as an alternative to the proposed rubble-mound breakwater at Noyo Bay, California.

Goals

The goals of this trip were primarily focussed on testing the new OSPREY design in the ART wave flume to obtain relevant data to aid in the evaluation of the technology. The wave transmission characteristics of the OSPREY were measured and are evaluated in this report. Transmission tests were conducted in the ART flume for a variety of regular and irregular wave conditions. The regular wave test results are compared to the transmission test data of Smith and Hennington (1995), who tested several rubble-mound alternatives for the proposed Noyo Bay detached breakwater.

The trip reported herein also included measurements of the oscillating water column free surface displacements within the OSPREY along with air pressure from inside the chamber. These data can be used to determine the power output of the OWC. Forces on the unit were measured using pressure transducers mounted on the face and a load table mounted under the model OSPREY. The power output and force data will be reviewed in a separate report.

Background

The OSPREY concept was developed by ART of Inverness, Scotland. The OSPREY I was a steel caisson fitted with electrical power generating turbines (Figures 1 and 2) Hagerman (1995a,b). The main power generation is based on the oscillating water column (OWC) concept, idealized in Figure 3.

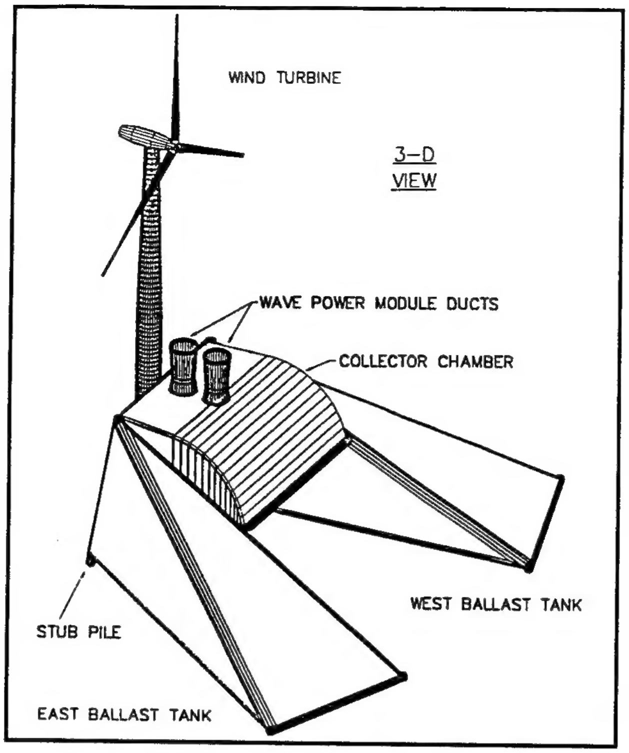


Figure 1. Osprey

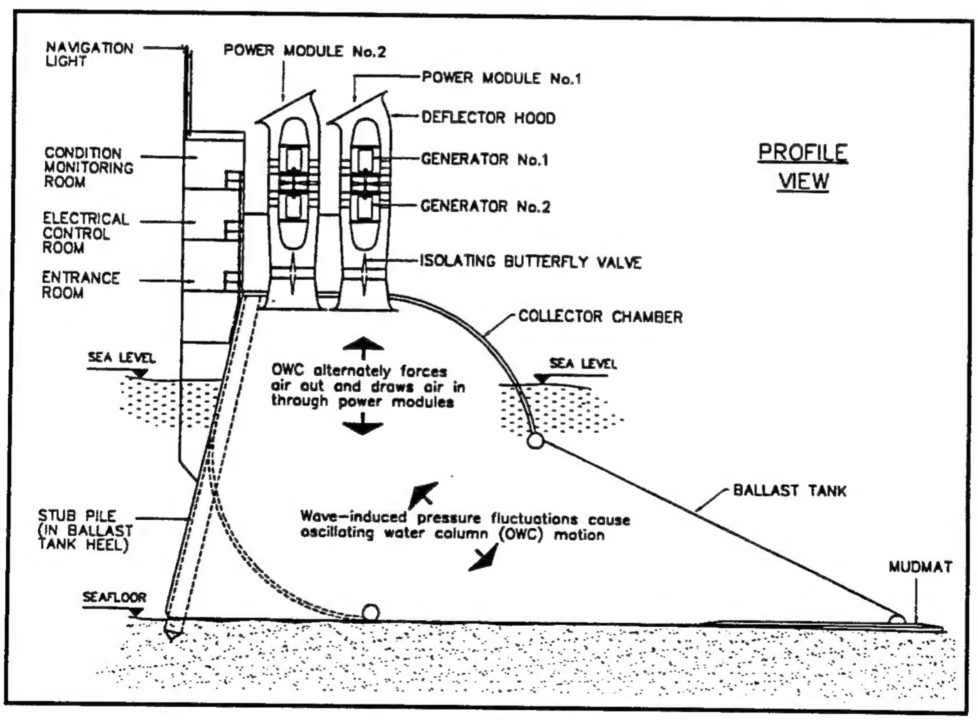


Figure 2. Elevation view of OSPREY 1 showing OWC and turbines

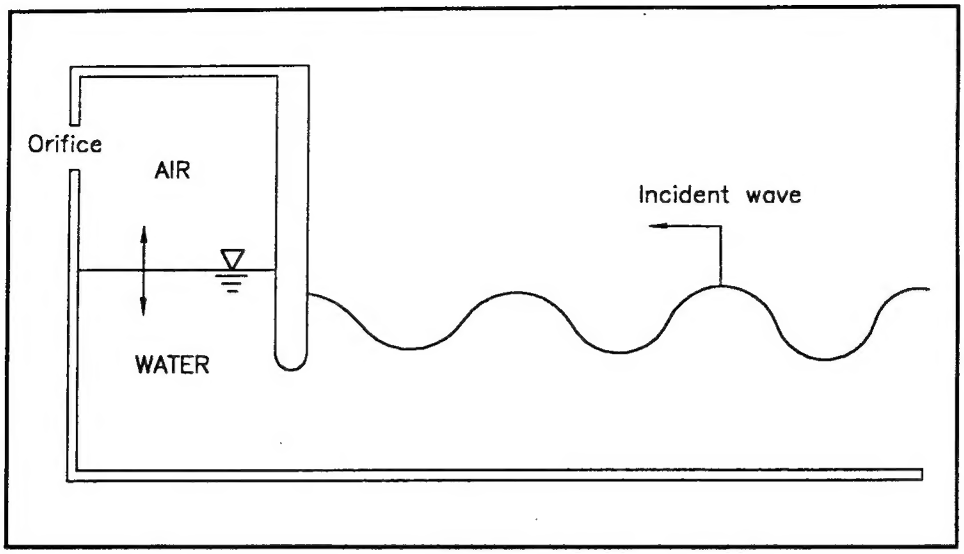


Figure 3. Idealized schematic of OWC

Incident waves force the rise and fall of the water column inside the caisson which drives air back and forth through a turbine. The OSPREY design utilized a steel superstructure integrating ballasting chambers and a capture chamber into a stand-alone, electrical power generation plant. The capture chamber geometry closely resembled the "harbor OWC" design which Koola, Ravindran, and Aswathanarayana (1994) reported as being optimal for environments with waves of varying frequencies. The OSPREY 1 design allowed the attachment of two Wells turbines for power generation. The Wells turbine is designed with symmetric aerofoils that have no inclination to the plane of rotation such that the turbine will be driven in the same rotational direction regardless of the direction of axial flow (Figure 4). As a result, the turbine is able to generate power independent of the direction of air flow through the device. Although the Wells turbine has a low efficiency due to the small magnitude of the force vector driving the turbine, the efficiency can be enhanced by what has been coined an "antenna focusing" effect. Although this focusing effect has not yet been supported by prototype data, the theory suggests that wave energy can be extracted from a broader length of wave crest than the width of the capture chamber opening (Figure 5). The interference of the incident wave train and waves radiating away from the OWC is believed to produce wave focussing. Capture ratios, defined as the ratio of the length of wave crest from which energy is being extracted to the chamber width, can be greater than one, but typically are not. The theory assumes some resonance between the OWC and the incident wave; so the degree of wave focussing is wave period dependent.

In 1995, a prototype OSPREY was constructed; the OSPREY 1. The structure was towed to and deployed off the north coast of Scotland. But, deteriorating weather conditions coupled with foundation and ballasting complications during the filling of the ballast tanks led to structural failure of the device before the unit could be brought on-line.

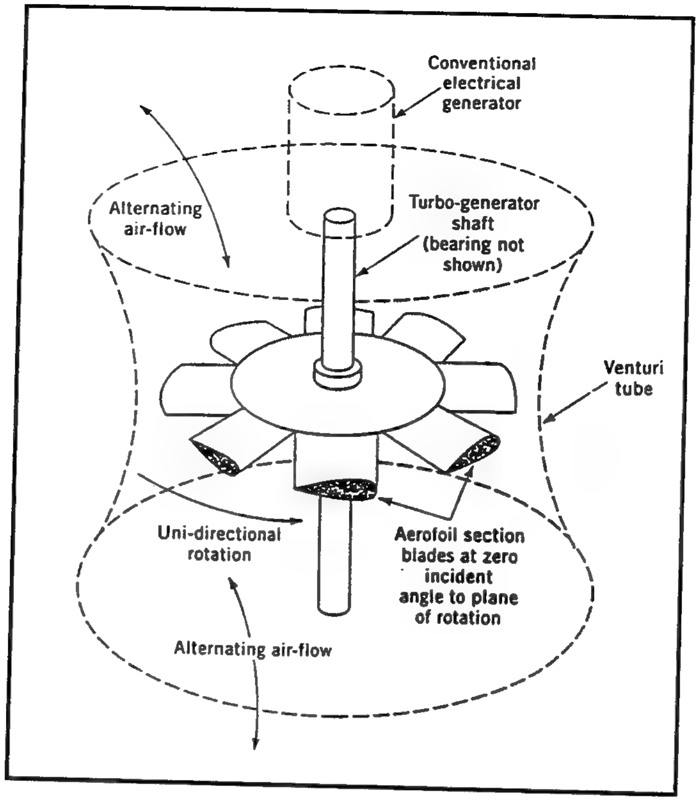


Figure 4. Wells turbine/generator

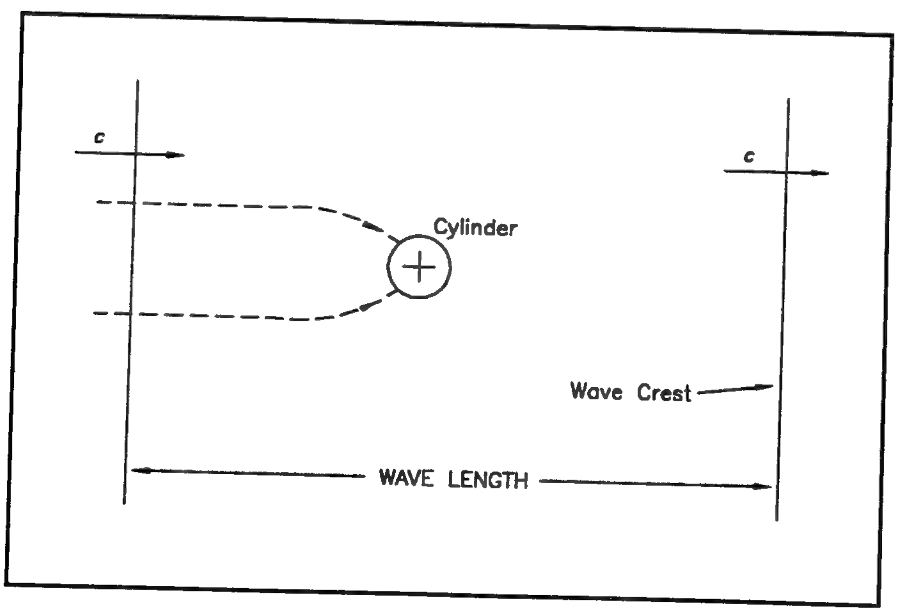


Figure 5. Conceptual drawing showing "antenna focussing"

Following failure of the OSPREY I prototype, and in light of its high construction costs, ART began testing new model configurations. The OSPREY model units as tested during the visit described herein differed significantly in geometry from the design shown in Figure 2. Some aspects of the new design were proprietary and cannot be shown; but the new design was simpler, being constructed of four cylinders connected in the shape of an 'A' to make two adjacent symmetrical chambers. The 'A' shape was open at the bottom of one leg which was oriented into the incident wave. The design tested used the two front inclined cylinders as OWCs and the rear two as ballasting chambers. The turbine ports were generally at the apex of the device. This new unit can be constructed of either concrete or steel, depending on which is less costly. Details of the new OSPREY design have not been finalized and variations, including inclined rectangular-shaped chambers rather than cylindrical chambers, continue to be investigated by ART. Therefore, it should be pointed out that, despite the deployment of a prototype unit in the summer of 1995, OSPREY technology is still in the developmental stage.

2 Experiment

Experimental Setup

The experiment consisted of both regular and irregular wave flume tests in the ART wave flume. The undistorted model-to-prototype length scale ratio was 1:48.7, and temporal parameters were computed based on Froude similitude. The flume measured 20 m long by 3 m wide by 2 m deep (Figure 6). The waves were generated with an electro-mechanical flap-type paddle hinged at the bottom and controlled by a PC. The wave paddle drive program included an algorithm for reflected wave absorption at the paddle. This was done by measuring forces on the paddle push-rod, which were monitored in real time. The control PC computed a compensating signal which was fed back into the primary control signal. The Bretschneider spectrum was used as a model for the irregular waves generated. The plywood flume bottom slope was generally 1V:25H, but steepened to 1V:20H in the vicinity of the structure. Synthetic fiber mats were placed at the flume end opposite the paddle to absorb waves.

Four resistance wire gauges were used to measure the free surface displacements seaward and shoreward of the structure. These *wave* gauges were set in two two-gauge arrays so that the incident and reflected waves could be separated (Figure 6). Also, for a number of tests, a single wave gauge was placed inside the OSPREY to measure the free surface oscillations within the unit. All of the wave gauges were calibrated prior to each test series by stepping the gauge in increments of approximately 1 cm using pre-cut plexiglass templates. The water depth was monitored between tests using a hand-held rule. Additional instrumentation included a load table mounted under the center of the flume to measure forces on the OSPREY, and pressure transducers mounted on the outside of the OSPREY to measure the pressure distribution on the seaward face of the caisson. A pressure transducer was also installed at the end of a small tube routed to the inside of the OWC to provide measurements of the OWC air pressure. The internal pressure measurements can be used, along with the internal free surface measurement, to calculate the maximum power output of the OSPREY. Free surface and pressure measurements were all sampled at 20 Hz. The model A-shaped OSPREY units were firmly attached to the plywood tank bottom with wood screws.

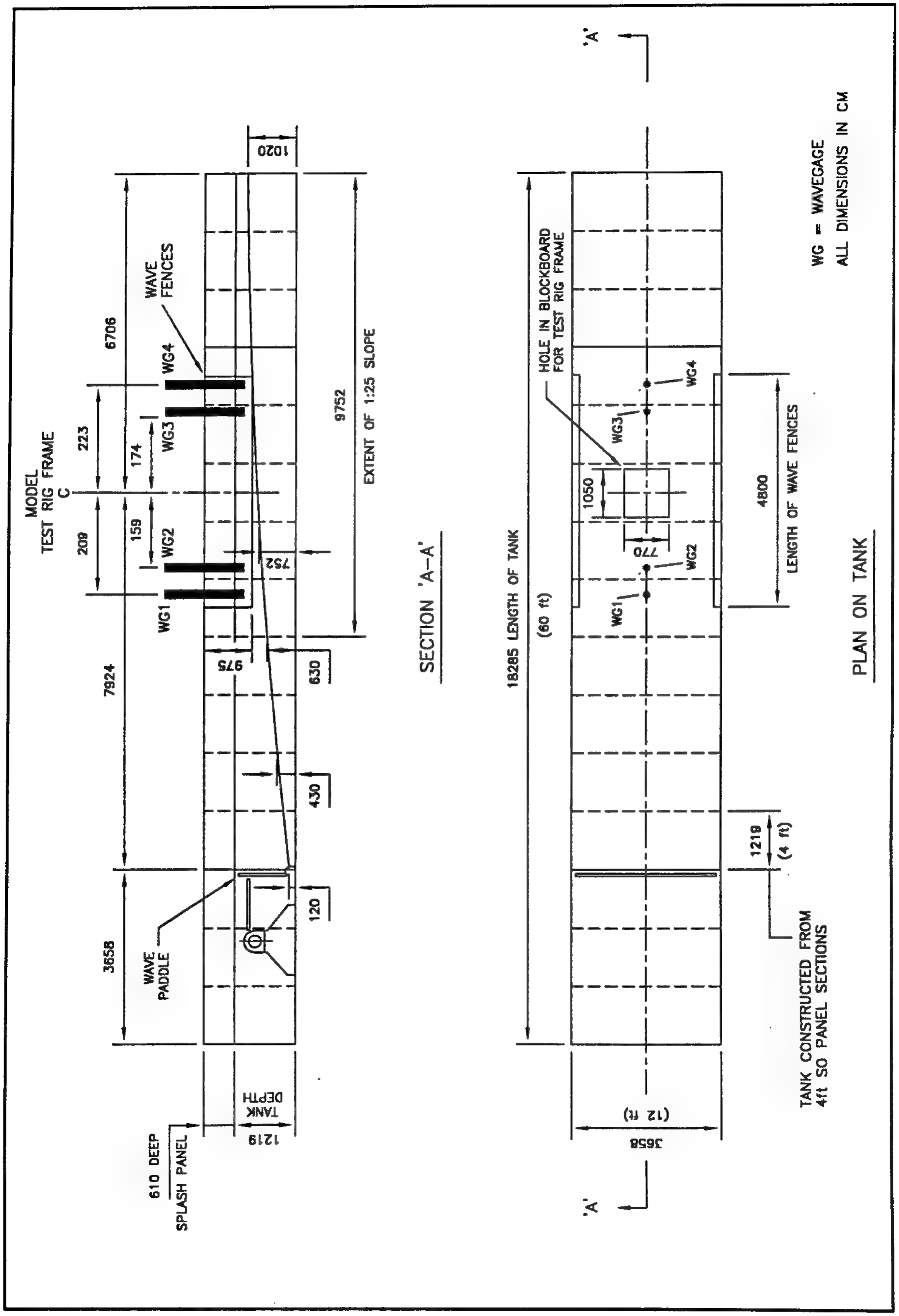


Figure 6. Wave flume plan and elevation views

The tests accomplished during the week of the trip are summarized in Appendix A in prototype scale units (Tables A1 and A2). As can be seen in Table A1, the following plans were tested.

Plan 1: Measured water surface elevations at four locations with no structure in flume for several test series of both regular and irregular waves.

Plan 2: Similar waves to Plan 1 except three OSPREY units were placed equidistant across flume midway between wave gauge pairs. Figure 7 shows a plan view of the structures in the flume in model units.

Plan 3: Similar waves to Plans 1 and 2 except four OSPREY units were placed equidistant across flume. Figure 8 shows a plan view of the structures in the flume in model units. Plan 3 also tested a high-tide condition.

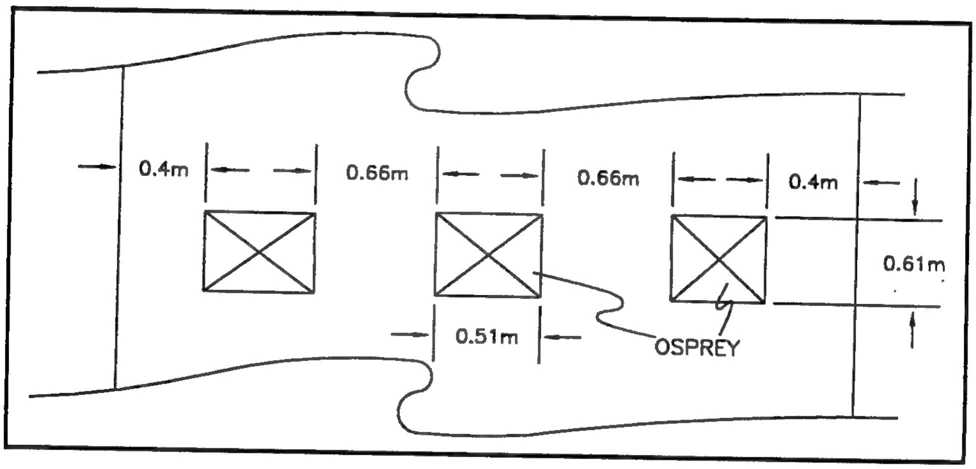


Figure 7. Plan 2: Three OSPREY in flume

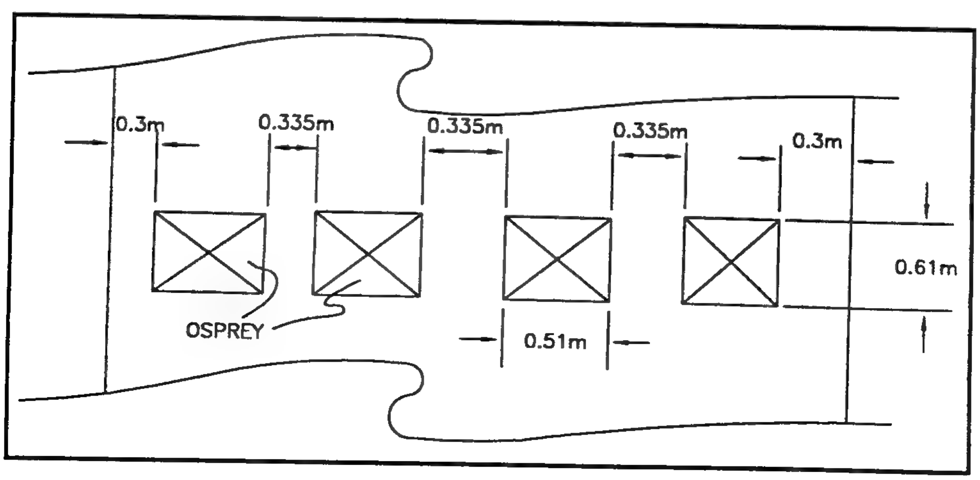


Figure 8. Plan 3: Four OSPREY in flume

The length along the axis of the footprint of the proposed rubble-mound breakwater, excluding the toe berm, is approximately 140 m (prototype). The approximate length along the crest of the structure is 122 m. Because the entire rubble mound will dissipate wave energy, the toe length was used to compute the necessary minimum length of the OSPREY array. Thus for the two arrays of OSPREY units tested, the array consisting of three units was spaced at 32.5 m while the array consisting of four units was spaced at 16 m. Following the visit by Corps personnel, an array consisting of five units spaced at both 4 m and 8 m was tested and transmission coefficients calculated. But these five-unit array tests will not be discussed herein. Table 1 summarizes array spacing utilized in the wave transmission tests conducted to date, along with the required capture ratio for 100 percent attenuation to be achieved.

Table 1. Spacing of OSPREY Arrays as Tested for Wave Transmission

Number of Units in Array	Spacing (m)	Required Capture Ratio for 100% Wave Attenuation
3 [1]	32.5	2.30
4 [1]	16	1.64
5 [2]	8	1.32
5 [2]	4	1.16

[1] Tested while Corps personnel were present.
[2] Tested with only ART personnel present.

Honeycomb-filled PVC pipes were used as dampers. These dampers were fitted to the top turbine port of the caisson to simulate the amount of damping due to viscous losses provided by the turbines. The dampers had been previously calibrated by ART to provide realistic levels of damping. As listed in Table A1, the number of dampers was varied to simulate various degrees of turbine power take-off.

Wave Data Analysis

The free surface oscillations measured in the two pairs of wave gauges were analyzed using several different methods, depending on the type of test. For all wave conditions, data from gauges 1 and 2 were used to compute the incident wave height and period. Data from gauges 3 and 4 were used to compute the transmitted wave height parameters.

Resolution of incident wave height and period

For regular waves, the incident waves were determined using two different time domain techniques:

R1. Compute average wave height H_I for each wave gauge, where H_I is the average of all peak-to-peak wave heights in the data file.

R2. Compute incident and reflected wave heights by least-squares fit of sinusoidal wave form to data and determining phase differences between two time series from pair of wave gauges (Mansard and Funke 1980). This method assumes the linear dispersion relations are valid. A modification of the basic technique also accounted for higher harmonics in the wave train, which are phase locked to the fundamental frequency.

ART technicians had previously calibrated the wave generation so that a variety of pre-specified prototype wave heights could be generated for several wave periods. These *intended* values are listed in the second two columns of Table A2. Because a new wave generation system had been installed, Plan 1 included several test series to verify this calibration with no structure in place. Figure 9 shows a typical regular wave time series with an intended 13-sec period and 6-m wave height (test RS136 in Tables A1 and A2). Method R1 average wave height H_I for gauge 2 was 7.7 m. Using method R2 with data from wave gauges 1 and 2, the incident average wave height was 6.9 m and the reflection coefficient was 0.02. Figure 10 shows a typical 20-sec regular wave with an intended wave height of 4 m (test RS204 in Tables A1 and A2). The average wave height for gauge 2 for this test was 4.4 m and the resolved incident wave height for gauges 1 and 2 was also 4.4 m with a reflection coefficient of 0.11. Figure 11 shows a plot of *intended* incident wave height versus measured for the regular wave test plans. As can be seen in the figure, the previous calibration was not as accurate as necessary to determine wave transmission. Therefore each wave data set was individually analyzed.

Figure 11 also shows that the two computation methods, R1 and R2, generally showed appreciable differences for smaller periods and converged for longer periods. The single gauge average wave heights of method R1 underpredicted wave heights determined using method R2. For many tests without the structure present, the reflection coefficients determined using method R2 were non-negligible, varying between 1 and 27 percent (Table A2). Method R1 can either under- or over-estimate the wave height, depending on where the wave gauge is in the reflected wave node field. Method R2 will tend to underestimate the wave height as the wave becomes more nonlinear. Because method R2 was generally greater than R1, it was determined that method R2 was generally more accurate than R1. Therefore, all regular wave heights listed in Table A2 were calculated using method R2. Note in Table A2 some reflection coefficients are not listed for 5-sec waves. This is because the gauges were spaced such that waves of this frequency could not be resolved. Inspection of Table A2 also reveals that several wave transmission coefficients exceeded one. This is most likely due to the wave shoaling between gauge pairs, particularly for waves that were breaking near the shallow gauge pair.

In order to match Smith and Hennington's (1995) previous transmission tests, prototype wave periods of 13 and 20 sec were intended to be generated.

Additionally, wave periods of 5 and 9 sec were desired. Prototype wave heights up to 9 m and 10 m were desired for the 13 and 20 sec waves; but the paddle was stroke limited for the higher periods. The largest regular waves measured at the structure produced an average wave height of 7 m for the 20-sec waves.

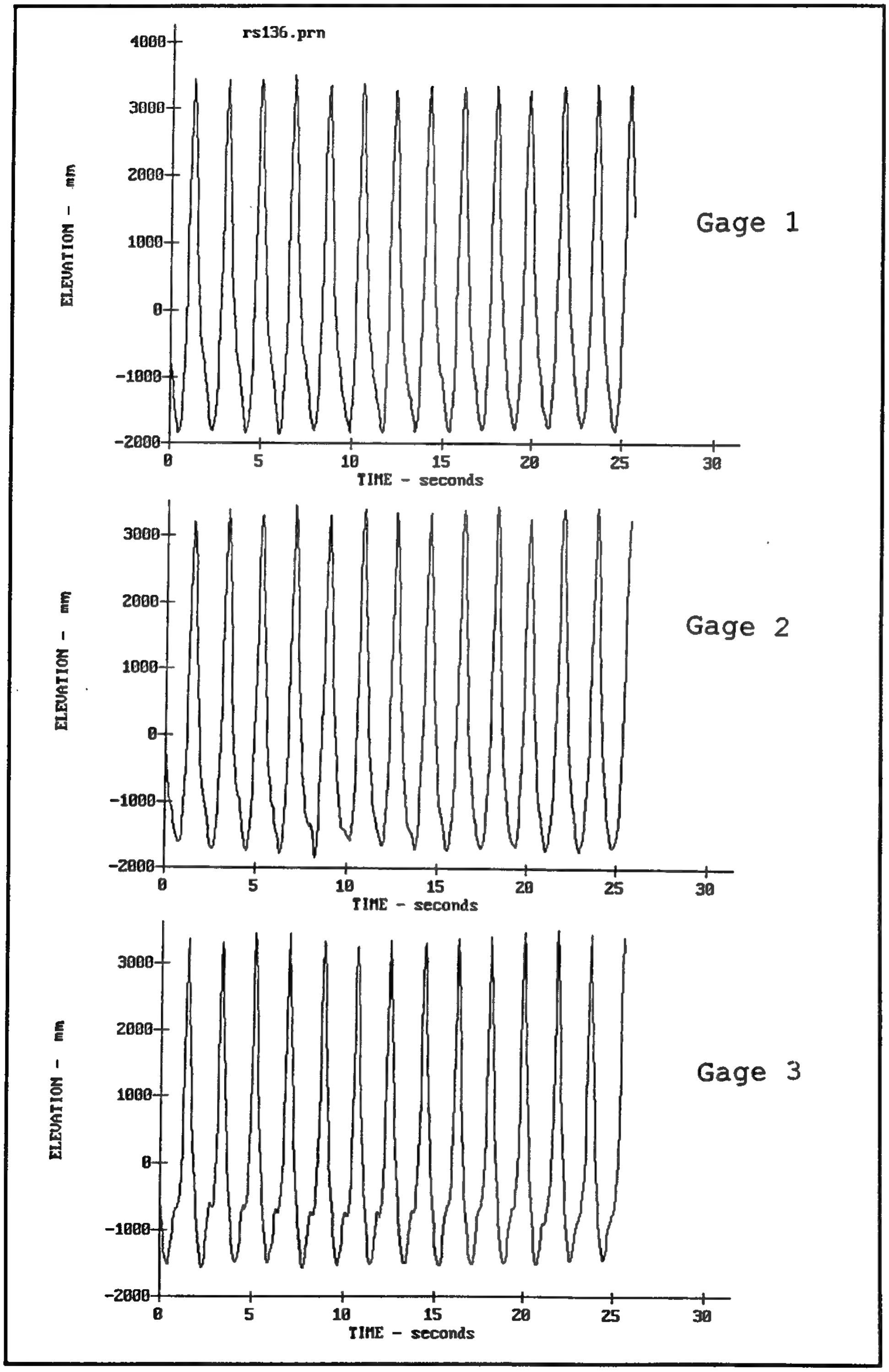


Figure 9. Wave gauge time series for 13-sec, 6-m regular wave test

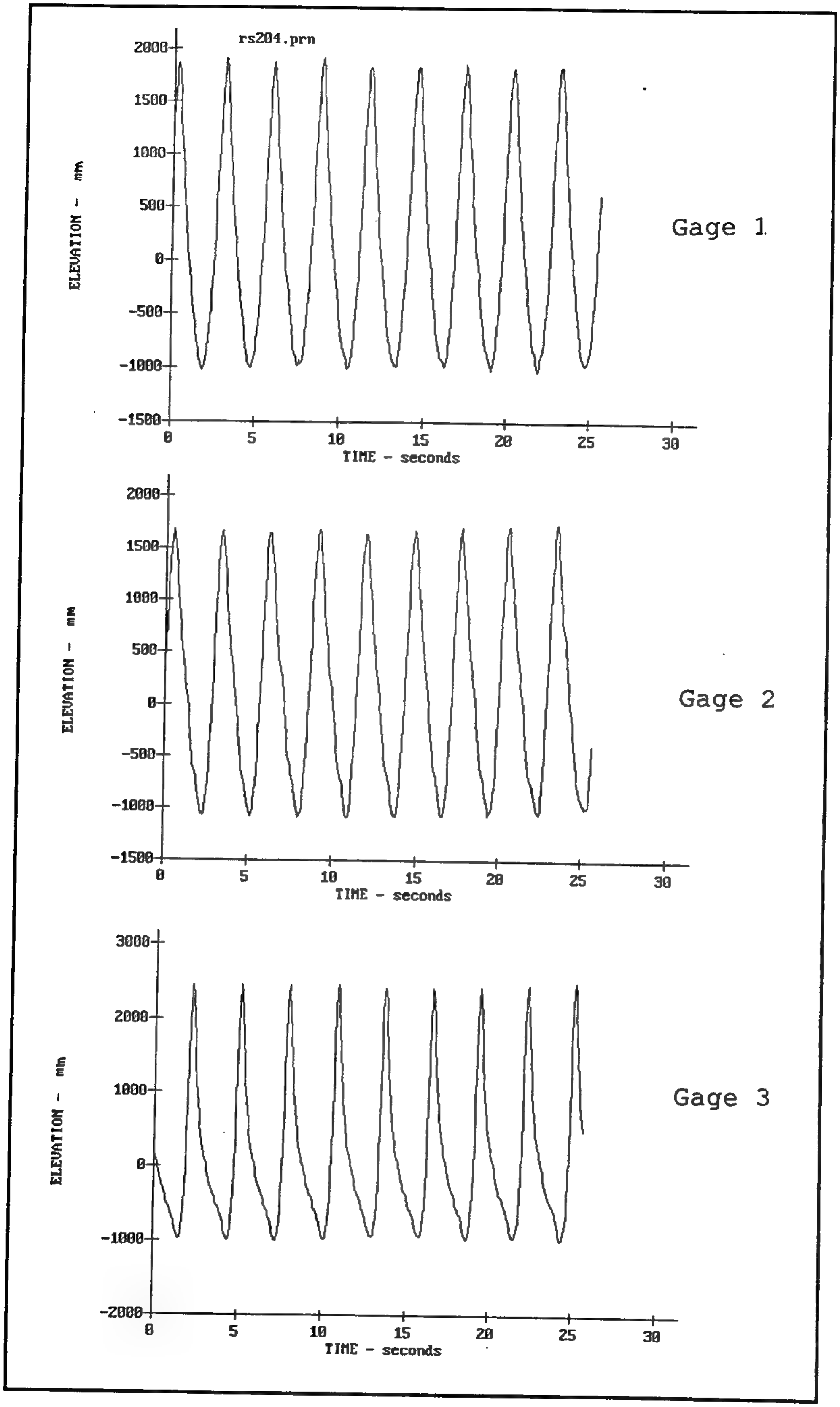
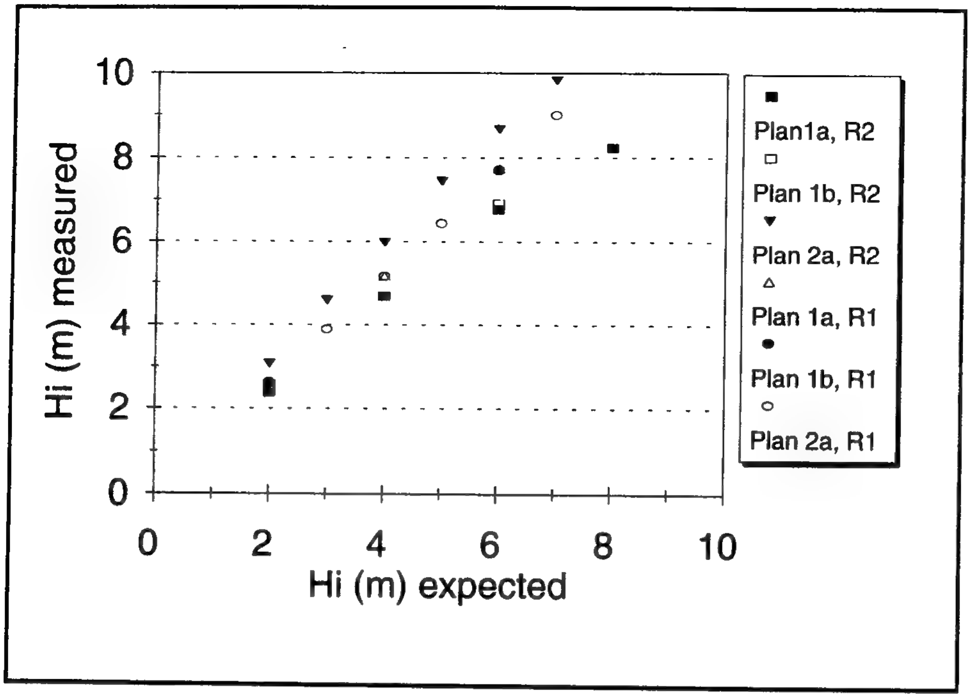
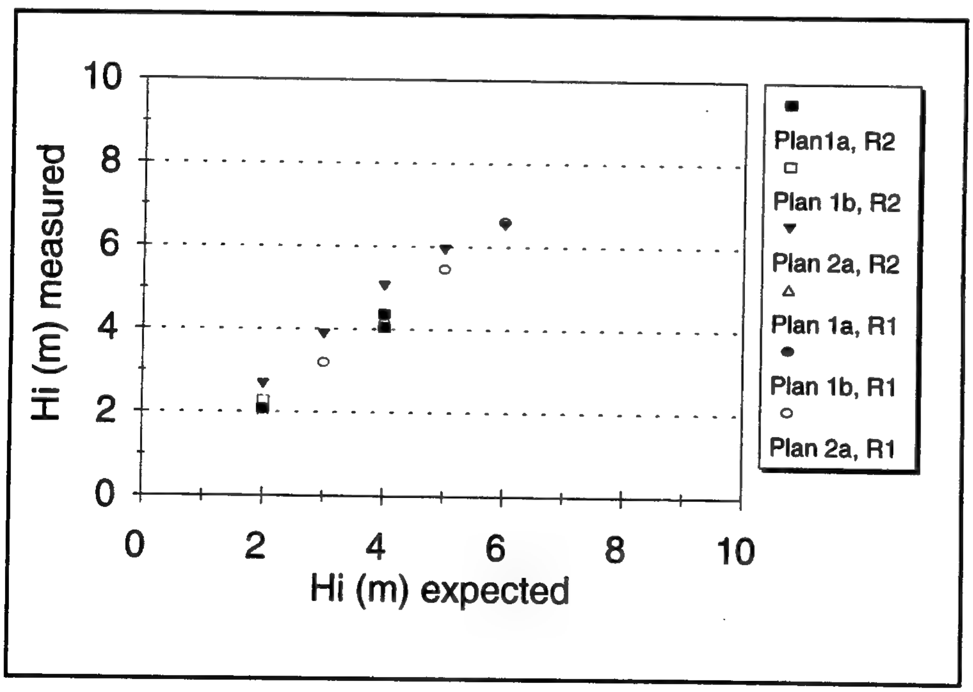


Figure 10. Wave gauge time series for 20-sec, 4-m regular wave test



a. 13-sec period



b. 20-sec period

Figure 11. Measured versus expected incident regular wave height with no structure in flume for various analysis methods

For irregular waves, three methods for computing incident wave height were used, as follows:

I1. Compute zeroth moment wave height H_{mo} for each wave gauge using spectral analysis of the individual gauge signal.

I2. Compute incident and reflected wave heights using method of Mansard and Funke (1980) using data from pair of wave gauges.

I3. Compute incident and reflected wave heights using method of Goda and Suzuki (1976) using data from pair of wave gauges.

Here H_{mo} is the spectral wave height statistic defined as four times the square root of the zeroth moment of the wave energy density spectrum. This statistic is roughly equivalent to the average of the highest third of the wave heights, for irregular waves.

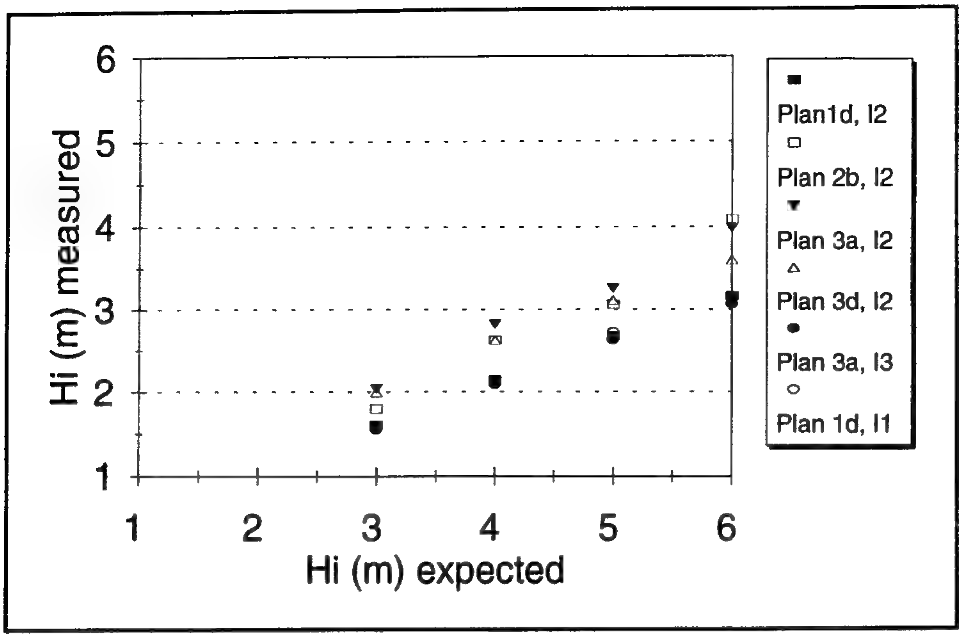
The spectral wave height was computed using the 1-percent cutoff values of the spectra. Using methods I2 and I3, the portion of the spectra where the coherence fell below 30 percent was discarded. If no coherence cutoff is used, the incident and reflected wave heights can be in error by more than 20 percent. This is primarily due to the large amount of energy in higher frequencies where the coherence is low. The sensitivity of the method to the coherence cutoff value was checked and there was no variability in the output for cutoff values between 20 and 80 percent. Thus, the cutoff coherence of 30 percent was used for all reflected wave analyses.

Irregular wave heights H_{mo} were limited to 4 m in height for both the 13 and 20 sec periods, due to stroke limitations.

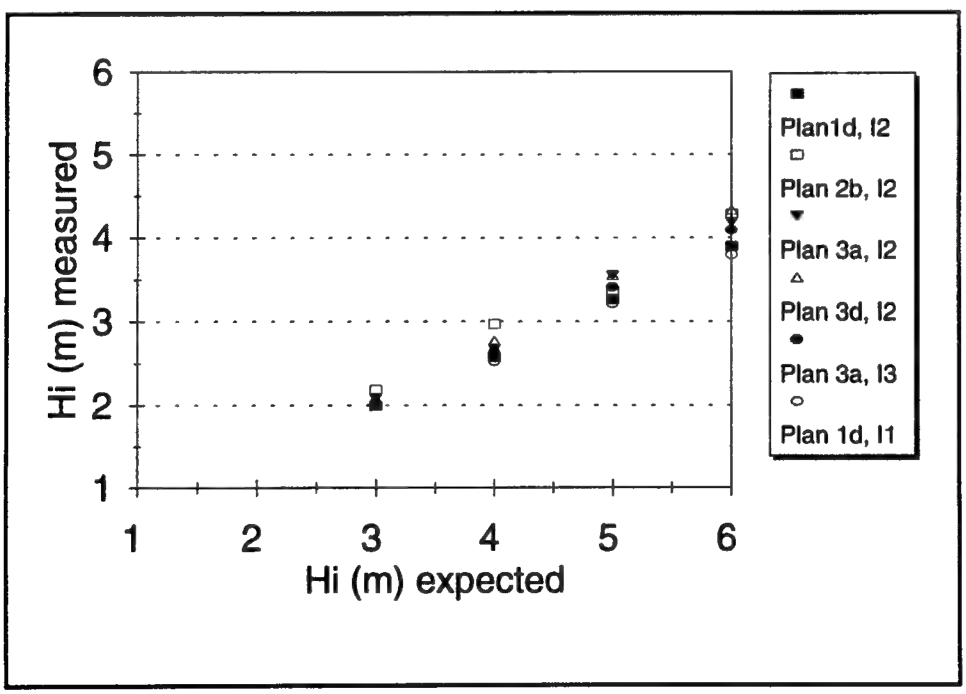
The individual gauge values agreed well with the reflected wave analysis results for plans when no structure was present. Figure 12 shows *intended* wave height versus measured for irregular wave tests using the analysis methods I1, I2, and I3. Method I2 was remarkably reliable, evidenced by the fact that results with and without structures present agree. Method I3 was unreliable under these conditions. Because method I1 cannot be used when appreciable reflected waves are present, only results from method I2 are shown in Table A2 for irregular wave height data.

Resolution of transmitted wave height and period

The transmitted wave height was determined from gauge 3 data for both regular and irregular waves using method R1 or I1, respectively. This is because waves were often breaking around gauges 3 and 4, making the output from the linear analyses of methods I2 and I3 unreliable.

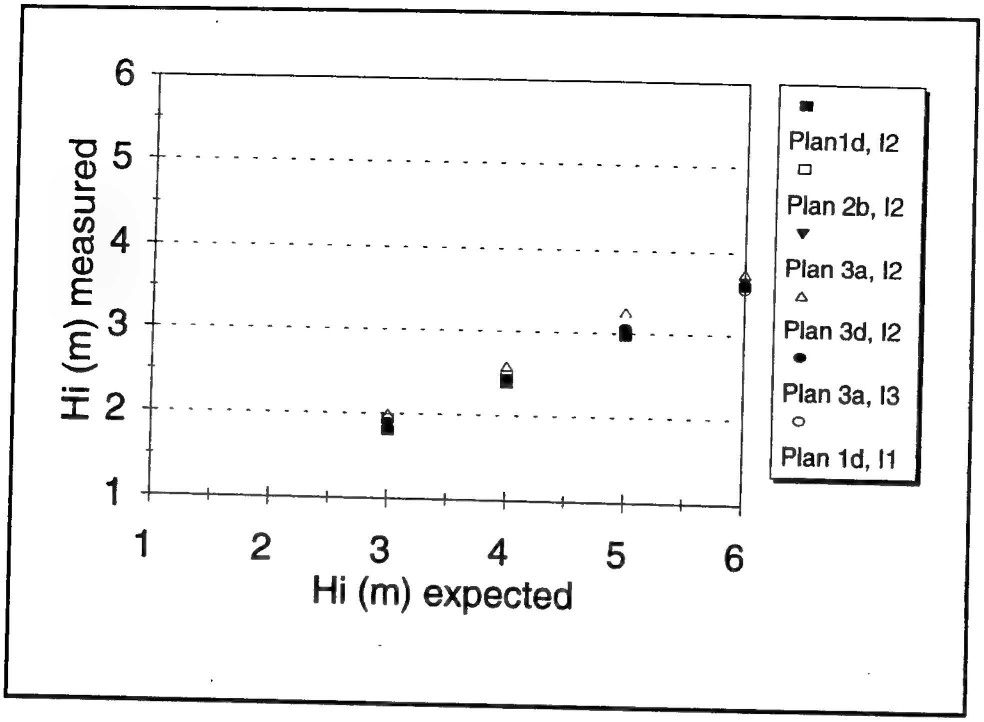


a. 9-sec period



b. 13-sec period

Figure 12. Measured versus expected incident irregular wave height with three OSPREY in flume for various analysis methods (continued)



c. 20-sec period

Figure 12. (concluded)

Wave Transmission Characteristics

Comparison of rubble-mound breakwater and OSPREY regular wave transmission characteristics

Figures 13 and 14 show incident versus transmitted regular wave heights for 13- and 20-sec periods. The wave heights are computed as averages from the time series. The figures compare data from the OSPREY experiment and from Smith and Hennington (1995). The OSPREY data are from Plan 2a where there were three OSPREY in the flume. The rubble-mound transmission characteristics are approximately the same for the two wave periods; but the OSPREY array shows considerable variation. The OSPREY transmitted wave height for the 20-sec wave is approximately 30 percent higher than for the 13-sec wave for the smaller waves, ranging to 75 percent higher for the larger waves. This is a characteristic of segmented breakwaters and is due to gap diffraction.

Comparing the rubble mound with the OSPREY, Table 2 lists the approximate transmission coefficients for the two breakwater options. Based on these results, the three-OSPREY array allowed approximately 54 and 69 percent more transmitted energy than the rubble-mound breakwater for 13- and 20-sec period

waves, respectively. This additional transmitted energy was in general passed between the separated OSPREY units in the array. The transmission coefficient of 1.0 for Plan 2 with 20-sec waves was probably due to the combined effects

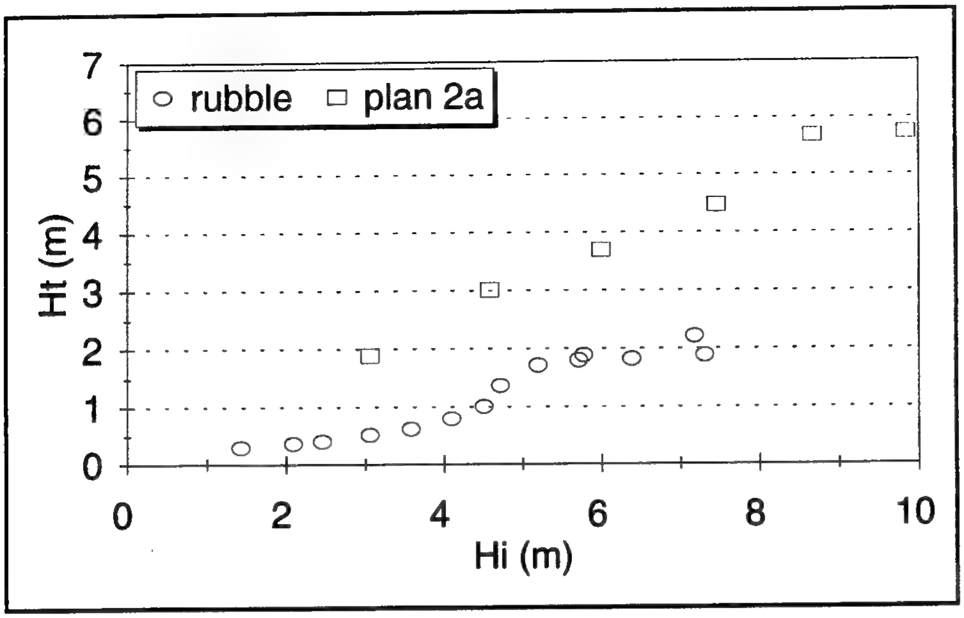


Figure 13. Incident versus transmitted regular wave height for 13-sec period. Three OSPREY compared to rubble mound

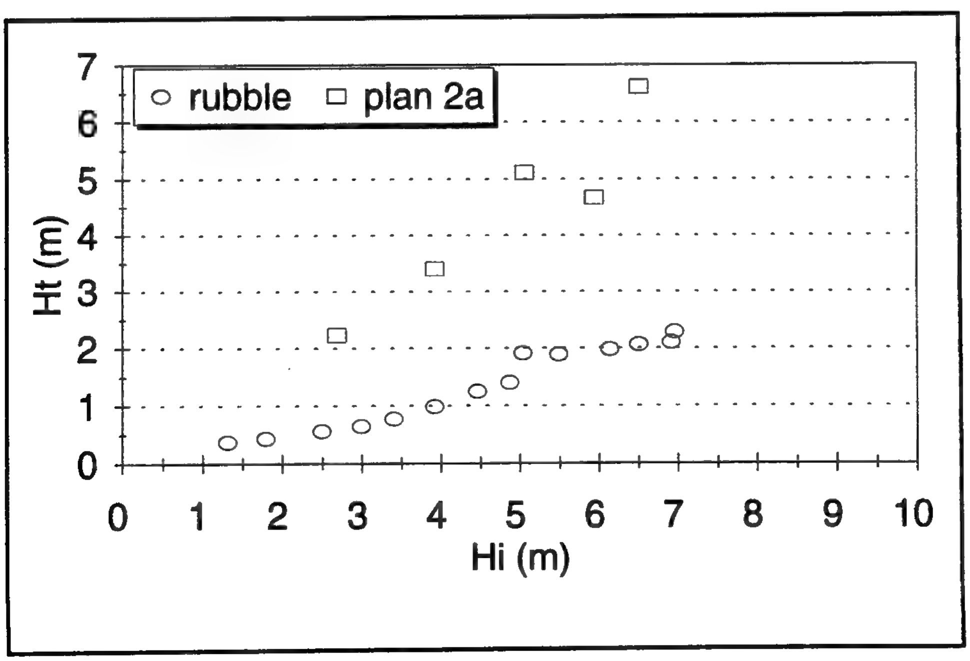


Figure 14. Incident versus transmitted regular wave height for 20-sec period. Three OSPREY compared to rubble-mound

of a large fraction of the incident wave energy being transmitted and shoaling between the gauges.

Table 2. Approximate Transmission Coefficients for Regular Wave Flume Tests, 16 m Prototype Depth		
Wave Period sec	Transmission Coefficient, *Ht/Hi*	
	Rubble-Mound Breakwater	Plan 2: Three-Unit OSPREY Array
13	0.29	0.63
20	0.31	1.0

Irregular wave transmission characteristics

Figures 15 through 17 show the results of the irregular wave transmission tests for the three-unit and four-unit OSPREY arrays. The approximate transmission coefficients are summarized in Table 3. It is clear that the four-unit array is more effective than the three-unit array. Changing the number of dampers produced very little noticeable effect on the transmitted wave height.

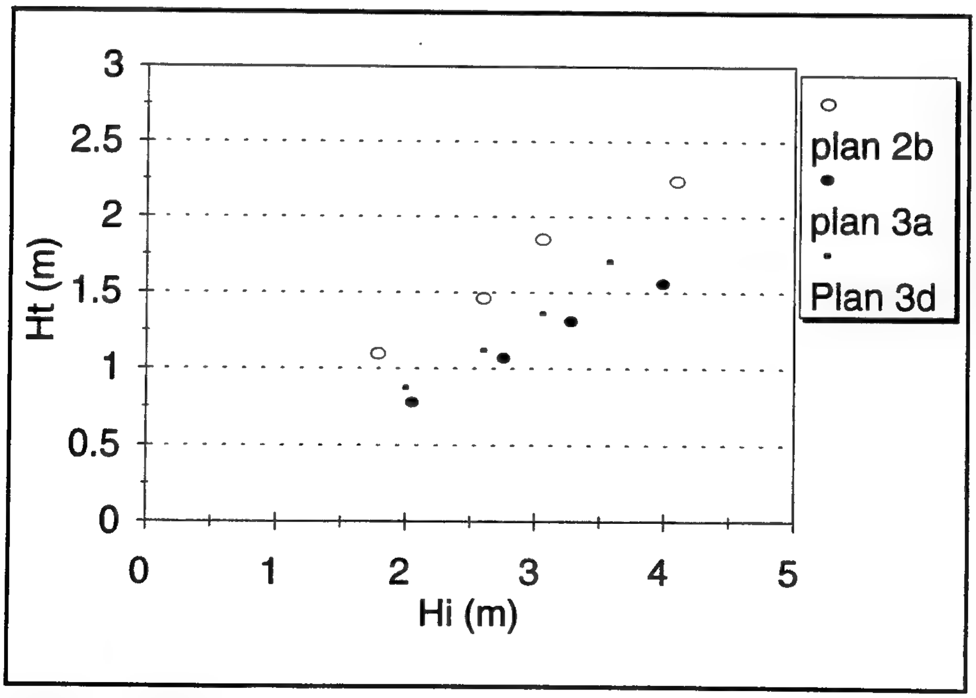


Figure 15. Incident versus transmitted irregular wave height for 9-sec period. Three OSPREY compared to four OSPREY

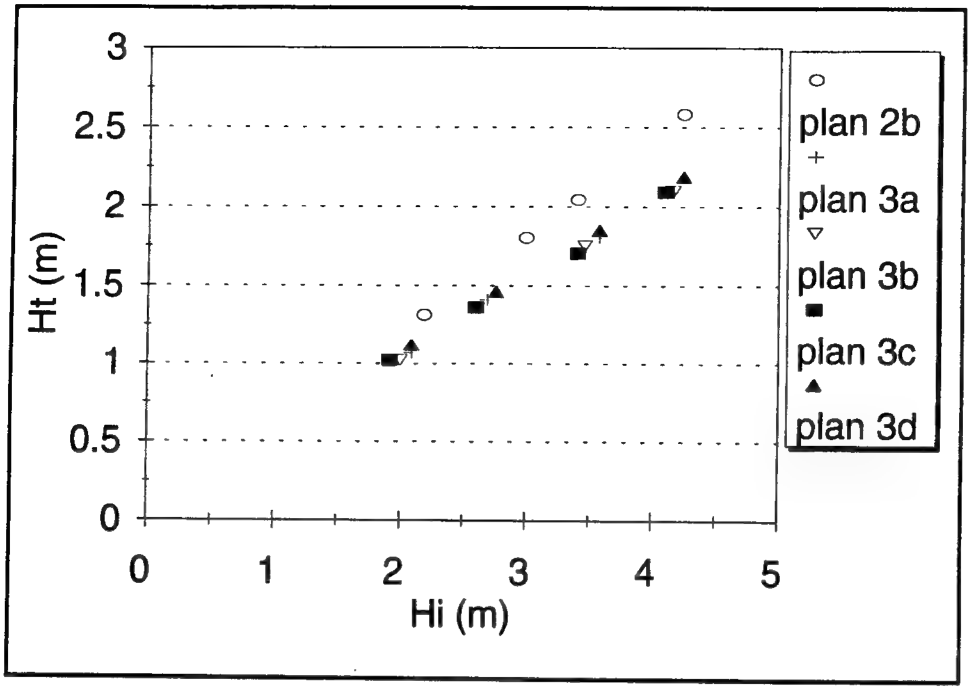


Figure 16. Incident versus transmitted irregular wave height for 13-sec period. Three OSPREY compared to four OSPREY

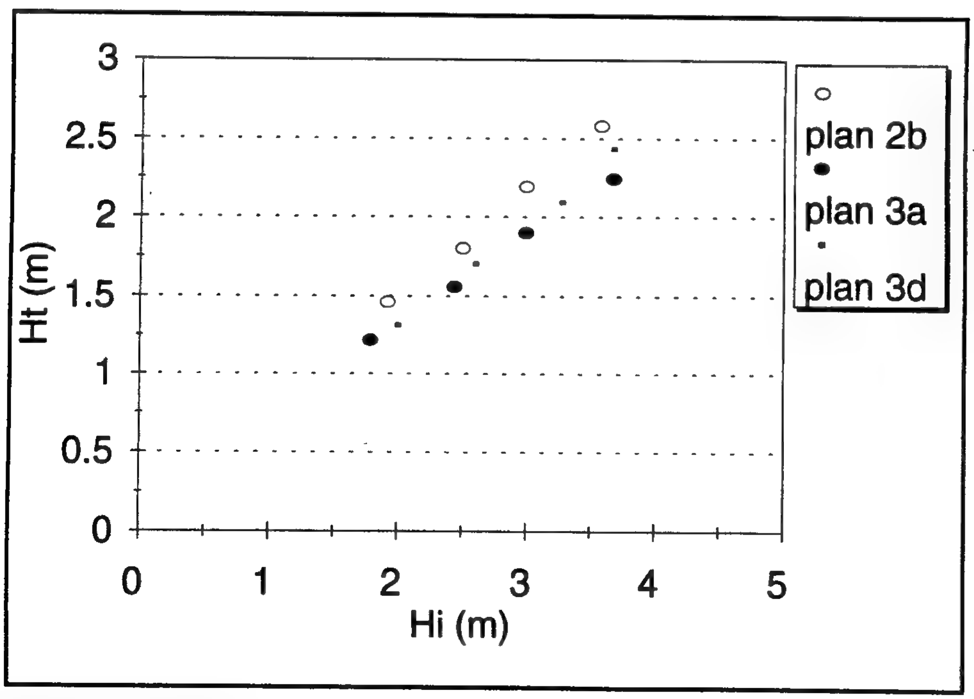


Figure 17. Incident versus transmitted irregular wave height for 20-sec period. Three OSPREY compared to four OSPREY

Table 3. Approximate Transmission Coefficients for Irregular Wave OSPREY Flume Tests

Wave Period sec	Plan 2b: Three-Unit OSPREY Array	Plan 3: Four-Unit OSPREY Array			
		Plan 3a: 1 damper, 16 m depth	Plan 3b: 2 damper, 18 m depth	Plan 3c: 3 damper, 18 m depth	Plan 3d: 1 damper, 18 m depth
9	0.56	0.40	--------	--------	0.47
13	0.62	0.52	0.52	0.52	0.52
20	0.72	0.61	--------	--------	0.66

3 Conclusions

Applied Research and Technology (ART), of Inverness, Scotland, previously developed and deployed the OSPREY 1, a stand-alone, electrical power generating steel caisson. The OSPREY 1 utilized an oscillating water column chamber fitted with Wells turbines. The device failed structurally before it could be made operational and ART proceeded to develop several new OSPREY designs. The OSPREY concept has been proposed as an alternative to the rubble-mound breakwater at Noyo Bay, California.

This report discusses wave flume tests of a newly designed OSPREY wave power generating caisson to assess its suitability and efficiency. The tests were carried out in the newly commissioned ART wave flume. Data from both regular and irregular wave tests are shown. Wave transmission test results are plotted and compared with previous tests of a proposed rubble-mound alternative.

For regular wave tests, the three-unit OSPREY array produced transmission coefficients 117 and 226 percent greater than the rubble-mound breakwater, for similar tests at periods of 13 and 20 sec, respectively. The rubble-mound transmission was not measured directly for irregular waves.

For irregular wave tests, the three-unit OSPREY array transmission coefficient was similar in magnitude to the OSPREY regular wave transmission coefficient for the 13-sec waves; but decreased by 28 percent for the 20 sec waves. Adding an additional OSPREY to the array reduced the OSPREY transmission coefficient by 15 to 30 percent. The higher reduction was for the 9-sec period waves while the lesser reduction was for the 13- and 20-sec waves, as expected. Additional damping using baffles on the turbine port of the OSPREY produced little noticeable effect on the transmitted wave height.

Based on the test results described above, and as would be expected, the three-unit and four-unit OSPREY arrays allowed significantly more wave energy transmission than the rubble-mound breakwater. It appears that in order to satisfy the basic requirements for wave sheltering at this site, the OSPREY units would have to be placed closer together, integrated within the rubble mound, or spaced using integrated inactive caissons.

References

Goda, Y., and Suzuki, Y. (1976). "Estimation of incident and reflected waves in random wave experiments." *Proc of the 15th Coastal Engineering Conf.*, American Society of Civil Engineers, New York.

Hagerman, G. (1995a). "Record-setting wave power plant deployed off Northern Scotland." *Sea Technology,* Sep 1995.

Hagerman, G. (1995b). "OSPREY update." submitted to *Hydro Review Worldwide,* Nov 1995.

Koola, Ravindran, and Aswathanarayana (1994) "Studies of the relative performance of three oscillating water column wave energy devices." *Journal of Energy Resources Technology*, v. 116, p.287-289.

Mansard, E. P., and Funke, E.R. (1980). "The measurement of incident and reflected spectra using a least squares method." *Proc. of the 17th Coastal Engineering Conf.*, American Society of Civil Engineers, New York.

Smith, E.R., and Hennington, L. (1995). "Noyo Harbor, California, breakwater stability and transmission tests." Technical Report CERC-95-17, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Appendix A Experimental Results Summaries

TABLE A1. Experiment Log

General Experiment Notes

Wave flume is approximately 20m long, 3m wide, and 2m deep

The average slope from gage 1 to 3 was 1:20 but the slope was flat at the structure.

The slope from gage 3 to 4 was 1:25. at gages 1,2 it was 1V:20H.

There was no point gage so the water depth could not be measured acccurately.

The depth at the gages was measured daily, but the water level varied.

So the depth at the gages was not generally known with any precision.

The load table was giving a lot of noise, spikes and would respond to movement anywhere in the building.

So the load table runs made during the week of 3/18 were of no value.

The number of dampers was not varied until the last couple of runs. Usually the units had one damper.

Experiment Notes Specific To Each Test Series

3/18/96

PLAN1a, CALMONO1.ZIP

Wave transmission tests

No structures in tank

sampling at 20 hz

4 gages - all measuring water surface elevation

Depth at wave board - 91.8 cm (3.012 ft)

wave gages are 1.5ft or cm sep was 45.72 cm

channel	Depth cm	Along-flume Location m	Depth ft	Along Flume Location ft	contents
1	43.01	0.00	1.41	0.00	deepest wave gage
2	40.20	0.46	1.32	1.50	wave gage 2
3	24.51	3.84	0.80	12.60	wave gage 3
4	22.40	4.30	0.74	14.10	shallowest wave gage

run number	run name	Wave Type	Number of Data Points	Number of Dampers	Target Prototype Period sec	Target Prototype Wave Height m	Target Model Period sec	Target Model Wave Height cm
PLAN1a								
1	052.pm	mono	1800	N/A	5.00	2.00	0.72	4.11
2	054.pm	mono	1800	N/A	5.00	4.00	0.72	8.21
3	056.pm	mono	1800	N/A	5.00	6.00	0.72	12.32
4	132.pm	mono	4000	N/A	13.00	2.00	1.86	4.11
5	134.pm	mono	4000	N/A	13.00	4.00	1.86	8.21
6	136.pm	mono	4000	N/A	13.00	6.00	1.86	12.32
7	138.pm	mono	4000	N/A	13.00	8.00	1.86	16.43
8	202.pm	mono	3000	N/A	20.00	2.00	2.87	4.11
9	204.pm	mono	3000	N/A	20.00	4.00	2.87	8.21

* N/A stands for NOT APPLICABLE

TABLE A1. Experiment Log (Continued)								
3/19/96								
PLAN 1b, 1c, CALMONO1.ZIP and RAN3_19.ZIP								
Wave transmission tests								
no structures in tank								
sampling at 20 hz								
4 gages - all measuring water surface elevation in am								
Depth at wave board - 91.8 cm (3.012 ft)								
				Along-flume		**Along Flume**		
channel	**Depth**			**Location**	**Depth**	**Location**	**contents**	
	cm			**m**	**ft**	**ft**		
1	43.01			0.00	1.41	0.00	deepest wave gage 1	
2	40.20			0.46	1.32	1.50	wave gage 2	
3	24.51			3.84	0.80	12.60	wave gage 3	
4	22.40			4.30	0.74	14.10	shallowest wave gage	
		Wave	**Number**	**Number**	**Target**	**Target**	**Target**	**Target**
run		**Type**	**of Data**	**of**	**Prototype**	**Prototype**	**Model**	**Model**
number	**run name**		**Points**	**Dampers**	**Period**	**Wave Height**	**Period**	**Wave Height**
					sec	**m**	**sec**	**cm**
PLAN 1b, 1c								
1	RAN001.PRN	random	4400	N/A	12.92	5.00	1.85	10.27
2	RS052	mono	600	N/A	5.00	2.00	0.72	4.11
3	RS056	mono	600	N/A	5.00	6.00	0.72	12.32
4	RS132	mono	600	N/A	13.00	2.00	1.86	4.11
5	RS136	mono	600	N/A	13.00	6.00	1.86	12.32
6	RS202	mono	600	N/A	20.00	2.00	2.87	4.11
7	RS204	mono	600	N/A	20.00	4.00	2.87	8.21
8	RS1794	mono	600	N/A	17.00	9.40	2.44	19.30
9	RAN002.PRN	random	4400	N/A	8.95	4.00	1.28	8.21
10	RAN003.PRN	random	4400	N/A	12.92	5.00	1.85	10.27

TABLE A1. Experiment Log (Continued)

3/19/96

PLAN 2a, CS1DAT01.ZIP

Wave transmission/attenuation and power capture tests

3 structures in tank, 0.4m from walls, 0.66m separation between models

model Osprey width is 0.5133m

sampling at 20 hz

7 gages - 4 measuring water surface elevation, redundant gage 3,

wave gage and pressure transducer in center model

Depth at wave board - 91.8 cm (3.012 ft)

channel	Depth			Along-flume Location	Depth	Along Flume Location	contents
	cm			m	ft	ft	
1	43.01			0.00	1.41	0.00	wave gage 1
2	40.20			0.46	1.32	1.50	wave gage 2
3	24.51			3.84	0.80	12.60	wave gage 3
5							redundant wave gage 3
6							chamber pressure in pasc
7							chamber water level
0							

run number	run name	Wave Type	Number of Data Points	Number of Dampers	Target Prototype Period	Target Prototype Wave Height	Target Model Period	Target Model Wave Height
					sec	m	sec	cm
PLAN 2a								
1	TT132	mono	1200	1	13.00	2.00	1.86	4.11
2	TT133	mono	1200	1	13.00	3.00	1.86	6.16
3	TT134	mono	1200	1	13.00	4.00	1.86	8.21
4	TT135	mono	1200	1	13.00	5.00	1.86	10.30
?	TT135c	mono	1200	1	13.00	5.00	1.86	10.27
5	TT136	mono	1200	1	13.00	6.00	1.86	12.32
6	TT137	mono	1200	1	13.00	7.00	1.86	14.37
7	TT202	mono	1200	1	20.00	2.00	2.87	4.11
8	TT203	mono	1200	1	20.00	3.00	2.87	6.16
9	TT204	mono	1200	1	20.00	4.00	2.87	8.21
10	TT205	mono	1200	1	20.00	5.00	2.87	10.27
11	TT206	mono	1200	1	20.00	6.00	2.87	12.32
12	BRET93	no exist		1	9.00	3.00	1.29	6.16
13	BRET94	no exist		1	9.00	4.00	1.29	8.21
14	BRET95	no exist		1	9.00	5.00	1.29	10.27
15	BRET96	no exist		1	9.00	6.00	1.29	12.32

TABLE A1. Experiment Log (Continued)

3/20/96
PLAN 2b, RAN3_20.ZIP
Wave transmission/attenuation and power capture tests
3 structures in tank, 0.4m from walls, 0.66m separation between models
model Osprey width is 0.5133m
sampling at 20 hz
7 gages - 4 measuring water surface elevation, redundant gage 3,
wave gage and pressure transducer in center model

channel	Depth cm	Along-flume Location m	Depth ft	Along Flume Location ft	contents
1	44.00	0.00	1.44	0.00	wave gage 1
2	41.50	0.46	1.36	1.50	wave gage 2
3	25.00	3.64	0.82	11.93	wave gage 3
4	23.10	4.09	0.76	13.43	wave gage 4
5					redundant wave gage 3
6					chamber pressure in pasc
7					chamber water level

run number	run name	Wave Type	Number of Data Points	Number of Dampers	Target Prototype Period sec	Target Prototype Wave Height m	Target Model Period sec	Target Model Wave Height cm
PLAN 2b								
1	RSBRET93	random	4200	1	9.00	3.00	1.29	6.16
2	RSBRET94	random	4200	1	9.00	4.00	1.29	8.21
3	RSBRET95	random	4200	1	9.00	5.00	1.29	10.27
4	RSBRET96	random	4200	1	9.00	6.00	1.29	12.32
5	RBRET133	random	4200	1	13.00	3.00	1.86	6.16
6	RBRET134	random	4200	1	13.00	4.00	1.86	8.21
7	RBRET135	random	4200	1	13.00	5.00	1.86	10.27
8	RBRET136	random	4200	1	13.00	6.00	1.86	12.32
9	RBRET203	random	4200	1	20.00	3.00	2.87	6.16
10	RBRET204	random	4200	1	20.00	4.00	2.87	8.21
11	RBRET205	random	4200	1	20.00	5.00	2.87	10.27
12	RBRET206	random	4200	1	20.00	6.00	2.87	12.32

TABLE A1. Experiment Log (Continued)

3/21/96
PLAN 1d, CS1DAT03.ZIP
Wave transmission/attenuation and power capture tests
no structures in tank
sampling at 20 hz
4 gages measuring water surface elevation

channel	Depth			Along-flume Location	Depth	Along Flume Location	contents
	cm			m	ft	ft	
1	44.00			0.00	1.44	0.00	wave gage 1
2	41.50			0.46	1.36	1.50	wave gage 2
3	25.00			3.64	0.82	11.93	wave gage 3
4	23.10			4.09	0.76	13.43	wave gage 4

run number	run name	Wave Type	Number of Data Points	Number of Dampers	Target Prototype Period	Target Prototype Wave Height	Target Model Period	Target Model Wave Height
					sec	m	sec	cm
PLAN 1d								
1	NMBRE93	random	4400	0	9.00	3.00	1.29	6.16
2	NMBRE94	random	4400	0	9.00	4.00	1.29	8.21
3	NMBRE95	random	4400	0	9.00	5.00	1.29	10.27
4	NMBRE96	random	4400	0	9.00	6.00	1.29	12.32
5	NMBRE133	random	4400	0	13.00	3.00	1.86	6.16
6	NMBRE134	random	4400	0	13.00	4.00	1.86	8.21
7	NMBRE135	random	4400	0	13.00	5.00	1.86	10.27
8	NMBRE136	random	4400	0	13.00	6.00	1.86	12.32
9	NMBRE203	random	4400	0	20.00	3.00	2.87	6.16
10	NMBRE204	random	4400	0	20.00	4.00	2.87	8.21
11	NMBRE205	random	4400	0	20.00	5.00	2.87	10.27
12	NMBRE206	random	4400	0	20.00	6.00	2.87	12.32

TABLE A1. Experiment Log (Continued)

3/21/96

PLANS 3a,b,c,d: CS1DAT04.ZIP through CS1DAT07.ZIP

Wave transmission/attenuation and power capture tests

4 structures in tank, 0.3m from walls, 0.335m separation between models

sampling at 20 hz

6 gages - 4 measuring water surface elevation

wave gage and pressure transducer in center model

channel	Depth			Along-flume Location	Depth	Along Flume Location	contents
	cm			m	ft	ft	
1	44.00			0.00	1.44	0.00	wave gage 1
2	41.50			0.46	1.36	1.50	wave gage 2
3	25.00			3.64	0.82	11.93	wave gage 3
4	23.10			4.09	0.76	13.43	wave gage 4
5							chamber pressure in pasc
6							chamber water level

run number	run name	Wave Type	Number of Data Points	Number of Dampers	Target Prototype Period	Target Prototype Wave Height	Target Model Period	Target Model Wave Height
					sec	m	sec	cm
PLAN 3a								
1	4BRE93	random	4400	1	9.00	3.00	1.29	6.16
2	4BRE94	random	4400	1	9.00	4.00	1.29	8.21
3	4BRE95	random	4400	1	9.00	5.00	1.29	10.27
4	4BRE96	random	4400	1	9.00	6.00	1.29	12.32
5	4BRE133	random	4400	1	13.00	3.00	1.86	6.16
6	4BRE134	random	4400	1	13.00	4.00	1.86	8.21
7	4BRE135	random	4400	1	13.00	5.00	1.86	10.27
8	4BRE136	random	4400	1	13.00	6.00	1.86	12.32
9	4BRE203	random	4400	1	20.00	3.00	2.87	6.16
10	4BRE204	random	4400	1	20.00	4.00	2.87	8.21
11	4BRE205	random	4400	1	20.00	5.00	2.87	10.27
12	4BRE206	random	4400	1	20.00	6.00	2.87	12.32

TABLE A1. Experiment Log (Continued)								
3/21/96								
Wave transmission/attenuation and power capture tests, high water (+1.8m), variable dampers								
4 structures in tank, 0.3m from walls, 0.335m separation between models								
sampling at 20 hz								
6 gages - 4 gages measuring water surface elevation								
wave gage and pressure transducer in center model								
				Along-flume		**Along Flume**		
channel	**Depth**			**Location**	**Depth**	**Location**	**contents**	
	cm			**m**	**ft**	**ft**		
1	47.70			0.00	1.56	0.00	wave gage 1	
2	45.20			0.46	1.48	1.50	wave gage 2	
3	28.70			3.64	0.94	11.93	wave gage 3	
4	26.80			4.09	0.88	13.43	wave gage 4	
5							chamber pressure in pasc	
6							chamber water level	
run number	**run name**	**Wave Type**	**Number of Data Points**	**Number of Dampers**	**Target Prototype Period**	**Target Prototype Wave Height**	**Target Model Period**	**Target Model Wave Height**
					sec	**m**	**sec**	**cm**
PLAN 3b								
1	4BRE133A	random	4400	2.00	13.00	3.00	1.86	6.16
2	4BRE134A	random	4400	2.00	13.00	4.00	1.86	8.21
3	4BRE135A	random	4400	2.00	13.00	5.00	1.86	10.27
4	4BRE136A	random	4400	2.00	13.00	6.00	1.86	12.32
PLAN 3c								
5	4BRE133B	random	4400	3.00	13.00	3.00	1.86	6.16
6	4BRE134B	random	4400	3.00	13.00	4.00	1.86	8.21
7	4BRE135B	random	4400	3.00	13.00	5.00	1.86	10.27
8	4BRE136B	random	4400	3.00	13.00	6.00	1.86	12.32
PLAN 3d								
9	4BRE93H	random	4400	1.00	9.00	3.00	1.29	6.16
10	4BRE94H	random	4400	1.00	9.00	4.00	1.29	8.21
11	4BRE95H	random	4400	1.00	9.00	5.00	1.29	10.27
12	4BRE96H	random	4400	1.00	9.00	6.00	1.29	12.32
13	4BRE133H	random	4400	1.00	13.00	3.00	1.86	6.16
14	4BRE134H	random	4400	1.00	13.00	4.00	1.86	8.21
15	4BRE135H	random	4400	1.00	13.00	5.00	1.86	10.27
16	4BRE136H	random	4400	1.00	13.00	6.00	1.86	12.32
17	4BRE203H	random	4400	1.00	20.00	3.00	2.87	6.16
18	4BRE204H	random	4400	1.00	20.00	4.00	2.87	8.21
19	4BRE205H	random	4400	1.00	20.00	5.00	2.87	10.27
20	4BRE206H	random	4400	1.00	20.00	6.00	2.87	12.32

Table A2. Experiment Results at Prototype Scale								
File Name	Intended wave period s	Intended wave height m	Measured wave period s	Measured incident wave height m	Measured reflected wave height m	Measured transmitte wave height m	Trans-mission Coeff. Ht/Hi	Reflectior Coeff. Hr/Hi
PLAN1a: CALMONO1.ZIP, no struc, regular								
052.prn	5	2	4.9	1.9				
054.prn	5	4	4.9	2.9				
056.prn	5	6	4.9	1.1				
132.prn	13	2	12.6	2.4	0.1	2.3	0.98	0.06
134.prn	13	4	12.6	4.7	0.2	4.7	1.00	0.04
136.prn	13	6	12.6	6.8	0.3	7.3	1.08	0.04
138.prn	13	8	12.7	8.2	0.2	7.9	0.96	0.03
202.prn	20	2	20.5	2.1	0.1	2.1	1.02	0.06
204.prn	20	4	20.5	4.0	0.2	4.6	1.14	0.06
PLAN1b: CALMONO2.ZIP, no struc, regular								
RS052	5	2	5.0	2.2				
RS056	5	6	5.0	2.4				
RS132	13	2	13.0	2.6	0.1	2.7	1.04	0.03
RS136	13	6	13.0	6.9	0.1	7.5	1.08	0.02
RS202	20	2	20.0	2.3	0.3	2.4	1.06	0.11
RS204	20	4	20.0	4.4	0.5	5.5	1.26	0.11
PLAN 1c: RAN3_19.ZIP, no struc, irreg								
RAN001.PRN	3	14	13.3	3.0	0.5	2.9	0.97	0.18
RAN002.PRN	2.4	9	5.4	2.5	1.6	2.3	0.90	0.63
RAN003.PRN	3.4	13	12.6	3.4	1.1	3.2	0.94	0.33
PLAN 1d: CS1DAT03.ZIP, no Struc, irreg								
NMBRE93	9	3	9.6	1.6	0.4	1.6	0.97	0.27
NMBRE94	9	4	9.6	2.1	0.4	2.1	0.98	0.21
NMBRE95	9	5	8.8	2.7	0.5	2.7	1.02	0.20
NMBRE96	9	6	9.6	3.2	0.5	3.1	0.98	0.16
NMBRE133	13	3	12.8	2.0	0.2	1.9	0.95	0.11
NMBRE134	13	4	12.8	2.6	0.3	2.4	0.94	0.12
NMBRE135	13	5	12.8	3.3	0.5	3.0	0.91	0.16
NMBRE136	13	6	12.8	3.9	0.7	3.6	0.91	0.17
NMBRE203	20	3	19.5	1.8	0.1	1.8	0.97	0.06
NMBRE204	20	4	19.5	2.4	0.1	2.2	0.92	0.06
NMBRE205	20	5	18.1	3.0	0.2	2.7	0.92	0.07
NMBRE206	20	6	16.7	3.6	0.2	3.2	0.89	0.07

Table A2. Experiment Results at Prototype Scale (Continued)

File Name	Intended wave period s	Intended wave height m	Measured wave period s	Measured incident wave height m	Measured reflected wave height m	Measured transmitte wave height m	Trans-mission Coeff. Ht/Hi	Reflectior Coeff. Hr/Hi
PLAN 2a: CS1DAT01.ZIP, Three struc, regular								
TT132	13	2	12.9	3.1	1.2	1.9	0.62	0.39
TT133	13	3	12.9	4.6	1.7	3.0	0.66	0.37
TT134	13	4	12.9	6.0	2.2	3.7	0.62	0.37
TT135	13	5	12.9	7.5	2.6	4.5	0.60	0.35
TT136	13	6	12.9	8.7	2.9	5.7	0.66	0.33
TT137	13	7	12.9	9.8	3.0	5.7	0.58	0.31
TT202	20	2	19.8	2.7	1.0	2.2	0.84	0.36
TT203	20	3	19.8	3.9	1.4	3.4	0.88	0.35
TT204	20	4	19.8	5.1	1.7	5.1	1.01	0.33
TT205	20	5	19.8	5.9	1.8	4.7	0.79	0.30
TT206	20	6	19.8	6.5	1.6	6.6	1.01	0.25
PLAN 2b: RAN3_20.ZIP, Three struc, irreg								
RSBRET93	9	3	9.6	1.8	0.6	1.1	0.61	0.35
RSBRET94	9	4	9.6	2.6	1.4	1.5	0.56	0.52
RSBRET95	9	5	8.8	3.1	1.1	1.9	0.60	0.37
RSBRET96	9	6	9.6	4.1	2.3	2.2	0.55	0.56
RBRET133	13	3	12.8	2.2	0.9	1.3	0.60	0.40
RBRET134	13	4	12.8	3.0	1.2	1.8	0.61	0.39
RBRET135	13	5	12.8	3.4	1.4	2.0	0.61	0.41
RBRET136	13	6	12.8	4.3	1.7	2.6	0.60	0.40
RBRET203	20	3	19.5	1.9	0.7	1.5	0.75	0.38
RBRET204	20	4	19.5	2.5	0.9	1.8	0.73	0.37
RBRET205	20	5	18.1	3.0	1.1	2.2	0.73	0.35
RBRET206	20	6	16.7	3.6	1.2	2.6	0.72	0.32

File Name	Intended wave period s	Intended wave height m	Measured wave period s	Measured incident wave height m	Measured reflected wave height m	Measured transmitte wave height m	Trans-mission Coeff. Ht/Hi	Reflectior Coeff. Hr/Hi
Table A2. Experiment Results at Prototype Scale (Continued)								
PLAN 3a: CS1DAT04 - CS1DAT07.ZIP, Four Struc, irreg								
4BRE93	9	3	9.6	2.0	1.6	0.8	0.38	0.76
4BRE94	9	4	9.6	2.8	2.1	1.1	0.38	0.74
4BRE95	9	5	8.8	3.3	1.9	1.3	0.40	0.60
4BRE96	9	6	9.6	4.0	2.7	1.6	0.39	0.68
4BRE133	13	3	12.8	2.1	1.1	1.1	0.51	0.53
4BRE134	13	4	12.8	2.7	1.3	1.4	0.53	0.47
4BRE135	13	5	12.8	3.6	1.8	1.8	0.51	0.51
4BRE136	13	6	12.8	4.2	1.9	2.1	0.50	0.44
4BRE203	20	3	19.5	1.8	0.9	1.2	0.68	0.49
4BRE204	20	4	19.5	2.4	1.2	1.6	0.64	0.48
4BRE205	20	5	18.1	3.0	1.5	1.9	0.63	0.48
4BRE206	20	6	16.7	3.7	1.7	2.2	0.61	0.45
PLAN3b								
4BRE133A	13	3	12.8	2.0	1.0	1.0	0.51	0.51
4BRE134A	13	4	12.8	2.6	1.2	1.4	0.52	0.46
4BRE135A	13	5	12.8	3.5	1.6	1.8	0.51	0.46
4BRE136A	13	6	12.8					
PLAN3c								
4BRE133B	13	3	12.8	1.9	1.0	1.0	0.53	0.53
4BRE134B	13	4	12.8	2.6	1.3	1.4	0.52	0.48
4BRE135B	13	5	12.8	3.4	1.7	1.7	0.50	0.49
4BRE136B	13	6	12.8	4.1	1.8	2.1	0.51	0.43
PLAN3d								
4BRE93H	9	3	9.6	2.0	1.3	0.9	0.44	0.66
4BRE94H	9	4	9.6	2.6	1.5	1.1	0.43	0.57
4BRE95H	9	5	8.8	3.1	1.7	1.4	0.44	0.53
4BRE96H	9	6	9.6	3.6	1.6	1.7	0.47	0.45
4BRE133H	13	3	12.8	2.1	1.0	1.1	0.53	0.49
4BRE134H	13	4	12.8	2.8	1.3	1.5	0.53	0.46
4BRE135H	13	5	12.8	3.6	1.6	1.9	0.52	0.45
4BRE136H	13	6	12.8	4.3	2.0	2.2	0.51	0.47
4BRE203H	20	3	19.5	2.0	0.9	1.3	0.66	0.46
4BRE204H	20	4	19.5	2.6	1.2	1.7	0.66	0.47
4BRE205H	20	5	18.1	3.3	1.6	2.1	0.64	0.49
4BRE206H	20	6	16.7	3.7	1.7	2.4	0.65	0.45

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1997

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Evaluation of Wave Transmission Characteristics of OSPREY Wave Power Plant for Noyo Bay, California

5. FUNDING NUMBERS

6. AUTHOR(S)
Jeffrey A. Melby, William Appleton

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199
U.S. Army Engineer District, San Francisco
333 Market Street, San Francisco, CA 94105-1905

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper CHL-97-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer District, San Francisco
333 Market Street
San Francisco, CA 94105-1905

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report discusses wave flume tests of a newly designed ocean swell powered renewable energy (OSPREY) wave power generating caisson to assess its suitability and efficiency. Tests were carried out in a new wave flume commissioned by Applied Research and Technology (ART), of Inverness, Scotland. Data from both regular and irregular wave tests are shown. Wave transmission test results are plotted and compared with previous tests of a proposed rubble-mound alternative. Test results indicate that three-unit and four-unit OSPREY arrays allow significantly more wave energy transmission than the rubble-mound breakwater. In order to satisfy the basic requirements for wave sheltering at this site, it would appear that the OSPREY units must be placed closer together, integrated within the rubble mound, or spaced using integrated inactive caissons.

14. SUBJECT TERMS

Electrical-power-generating caisson	Rubble-mound breakwaters
Noyo Bay	Wave transmission
OSPREY	

15. NUMBER OF PAGES
42

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT